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Review

# Why women see differently from the way men see? A review of sex differences in cognition and sports

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## Abstract

The differences of learning and memory between males and females have been well documented and confirmed by both human and animal studies. The sex differences in cognition started from early stage of neuronal development and last through entire lifespan. The major biological basis of the gender-dependent cognitive activity includes two major components: sex hormone and sex-related characteristics, such as sex-determining region of the Y chromosome (SRY) protein. However, the knowledge of how much biology of sex contributes to normal cognitive function and elite athletes in various sports are still pretty limited. In this review, we will be focusing on sex differences in spatial learning and memory – especially the role of male- and female-type cognitive behaviors in sports.

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**Keywords:** Brain; Hormones; Learning and memory in sports; Sex-specific cognition

## 1. Introduction

Differing performances between the sexes have been observed on a number of common learning tasks in both human and animal literature. There are four classes of memory tasks for which sex differences have been frequently reported: spatial, verbal, autobiographical, and emotional memory. Typically, it has been commonly believed that males show an advantage on spatial tasks, and females on verbal tasks. However, evidence now shows that the male spatial advantage does not apply to certain spatial tasks. Female advantage in verbal processing extends into many memory tasks which are not explicitly verbal.<sup>1</sup> In this session of review, we included studies of human spatial ability and verbal memory with sex-favored components (Table 1).

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## 2. Typical male-favored spatial cognitive behaviors

### 2.1. Mental rotation

The concept of mental rotation (spatial rotation) as a cognitive behavior was introduced by Shepard and Metzler<sup>2</sup> in 1971. It requires the dynamic spatial transformation of objects with respect to their internal spatial structure. Furthermore, mental rotation is involved in problem solving,<sup>3</sup> acquiring mathematical knowledge,<sup>4</sup> and academic thinking.<sup>5</sup> Studies using eye movement measurements, direct recording from electrodes implanted in the brain, functional magnetic resonance imaging (fMRI), and transcranial magnetic stimulation suggested that mental rotation involves motor and visual processes and related brain regions.<sup>6</sup> The typical test of mental rotation involves distinguishing a shape or an object that has been rotated from a similar, rotated shape or object, often a mirror image. There are simple (2-dimensional stimuli) and complex (3-dimensional stimuli) tasks as shown in Fig. 1. The rotation of simple 2-dimensional stimuli can lead to greater activation of the left parietal area of brain rather than the right parietal area, while the complex 3-dimensional rotations are associated with more right parietal activation than left parietal



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Table 1  
Sex differences in spatial learning and memory.

Author	Year	Case#	Age (year)	Favored	<i>p</i>
<b>Mental rotation</b>					
Sharps et al. <sup>76</sup>	1993	60	18–36	Male	<0.001
Epting and Overman <sup>77</sup>	1998	47	19–41	Male	<0.01
Moffat et al. <sup>78</sup>	1998	74	20s	Male	<0.001
Levine et al. <sup>79</sup>	1999	288	4–7	Male	<0.005
Silverman et al. <sup>80</sup>	2000	111	20s	Male	<0.001
Peters <sup>81</sup>	2005	212	20s	Male	<0.0001
Silverman et al. <sup>52</sup>	2007	95,742	20s–30s	Male	<0.05
Kaufman <sup>82</sup>	2007	100	16–18	Male	<0.0001
Maylor et al. <sup>83</sup>	2007	198,121	20–65	Male	<0.001
Jansen and Heil <sup>84</sup>	2010	150	20–70	Male	<0.01
Tzuriel and Egozi <sup>85</sup>	2010	116	6–7	Male	<0.01
Puts et al. <sup>25</sup>	2010	337	20s	Male	<0.0001
Lange-Kuttner and Ebersbach <sup>86</sup>	2013	97	6–9	Male	<0.05
Mantyla <sup>87</sup>	2013	72	19–40	Male	<0.01
Christie et al. <sup>88</sup>	2013	60	20s	Male	<0.05
<b>Navigation</b>					
Astur et al. <sup>89</sup>	1998	48	20s	Male	<0.05
Moffat et al. <sup>78</sup>	1998	74	20s	Male	<0.001
Silverman et al. <sup>80</sup>	2000	186	20s	Male	<0.001
Malinowski and Gillespie <sup>42</sup>	2001	1042	Unknown	Male	<0.001
Beatty <sup>90</sup>	2002	98	16–60	Male	<0.05
Driscoll et al. <sup>36</sup>	2005	70	20–60+	Male	<0.005
Postma et al. <sup>91</sup>	2004	64	20s	Male	<0.05
Tippett et al. <sup>92</sup>	2009	24	60–80	Male	<0.01
Chai and Jacobs <sup>93</sup>	2009	84	18–25	Male	<0.001
Vestergren et al. <sup>94</sup>	2012	1115	25–85	Male	<0.05
Persson et al. <sup>95</sup>	2013	24	18–35	Male	<0.05
<b>Object location</b>					
Portin et al. <sup>96</sup>	1995	389	62	Female	<0.001
McGivern et al. <sup>50</sup>	1997	483	10–20	Female	<0.0001
Epting and Overman <sup>77</sup>	1998	47	19–41	NS	NS
Postma et al. <sup>91</sup>	2004	64	20s	NS	NS
Herrera-Guzmán et al. <sup>97</sup>	2004	90	50–80	Female	<0.05
Silverman et al. <sup>52</sup>	2007	95,742	20s–30s	Female	<0.05
Ardila et al. <sup>98</sup>	2011	788	5–16	Female	<0.05
Bracco et al. <sup>99</sup>	2011	83	21–60	NS	NS
McGivern et al. <sup>100</sup>	2012	141	18–26	Female	<0.001
McGugin et al. <sup>55</sup>	2012	227	20s	Female	<0.001
<b>Verbal memory</b>					
Trahan and Quintana <sup>101</sup>	1990	140	Unknown	Female	<0.05
Mann et al. <sup>102</sup>	1990	175	Teens	Female	<0.001
Youngjohn et al. <sup>103</sup>	1991	1491	20–70	Female	<0.005
Savage and Gouvier <sup>104</sup>	1992	134	15–76	NS	NS
Portin et al. <sup>96</sup>	1995	389	62	Female	<0.005
Berenbaum et al. <sup>105</sup>	1997	57	20–40	Female	<0.05
Kimura and Clarke <sup>106</sup>	2002	81	20s	Female	<0.01
Yonker et al. <sup>107</sup>	2003	36	35–85	Female	<0.05
Kimura and Seal <sup>108</sup>	2003	53	Unknown	Female	<0.05
Neri et al. <sup>109</sup>	2012	900	65+	NS	NS
Munro et al. <sup>110</sup>	2012	957	67–89	Female	<0.001
Murre et al. <sup>111</sup>	2013	28,116	11–80	Female	<0.001
Heinzel et al. <sup>112</sup>	2013	523	51–82	Female	<0.001

activation.<sup>7</sup> Studies showed that the analogy between physical and mental processes requires activation of parietal area which is linked to angle of rotation.<sup>8</sup> Research on the early development appears that the mental rotation may appear as early as 4 months of age,<sup>9,10</sup> and reach near-adult level around the age of 6–7 years.<sup>11,12</sup>

### 2.1.1. Sex differences in mental rotation

Mental rotation has great sex differences, particularly males usually perform better on mental rotation tasks than do females.<sup>13</sup> However, the sex differences in mental rotation only appear in adults.<sup>7</sup> Interestingly, sex differences in mental rotation are also confirmed by brain imaging studies that showed different networks activating during mental rotation tasks for men and women, such as increased activation in the parietal lobules in men, and increased activity in frontal areas in women.<sup>14–16</sup> The unique brain regional activities between males and females may be interpreted as evidence of a different cognitive strategy between men and women to solve mental rotation problems. While it is unclear whether the sex difference in mental rotation is regulated or dependent on sex steroids, some studies showed that sex hormones play direct role in mental rotation. For example, in females, low estradiol during normal menstrual cycle was found to be associated with significantly better accuracy on the mental rotation task with large angles of rotation by 2-dimensional object, while estrogen showed no effects on small angles of rotation.<sup>17</sup> In contrast to estrogen, testosterone showed closely positive linkage to mental rotation. A recent study of women with polycystic ovary syndrome (PCOS), a disease characterized by elevated testosterone levels, showed a much better score in mental rotation task in women with PCOS compared to gender-matched normal controls.<sup>18</sup> Furthermore, within the PCOS group, the circulating levels of testosterone were significantly positively correlated with 3-dimensional scoring, whereas estradiol was significantly negatively correlated with 3-dimensional scoring. Furthermore, Aleman et al.<sup>19</sup> found that a single administration of testosterone in young women improved performance in a 3-dementia spatial rotation task. However, the relationship between testosterone levels and mental rotation in males are controversial. For instance, mental rotation was impaired in men with hypergonadotropic hypogonadism (androgen deficiency) compared to normal healthy male controls,<sup>20</sup> men with higher free testosterone levels performed better in mental rotation compared to control subjects,<sup>21</sup> and higher levels of salivary testosterone were associated with lower error rates and faster responses in mental rotation tests in young male adults,<sup>22</sup> suggesting mental rotation performance is positively related to testosterone levels in men. On the other hand, a study of 308 male twins showed that testosterone levels at age 14 (puberty) are significantly related to poor performance in mental rotation test in male young adults at age 21–23.<sup>23</sup> The negative relationship between testosterone levels and mental rotation performance is also reported in older males as higher testosterone levels correlated with poorer performance.<sup>24</sup> Furthermore, a study of salivary testosterone levels in 160 women and 177 men showed that circadian changes in testosterone were unrelated to changes in spatial performance in either sex.<sup>25</sup> Furthermore, the effects of sex hormones on mental rotation have also been investigated in people with transsexualism which individuals seek cross-gender treatment to change their sex. Studies found that untreated male-to-female transsexuals had better performance on 3-dimensional spatial rotation task

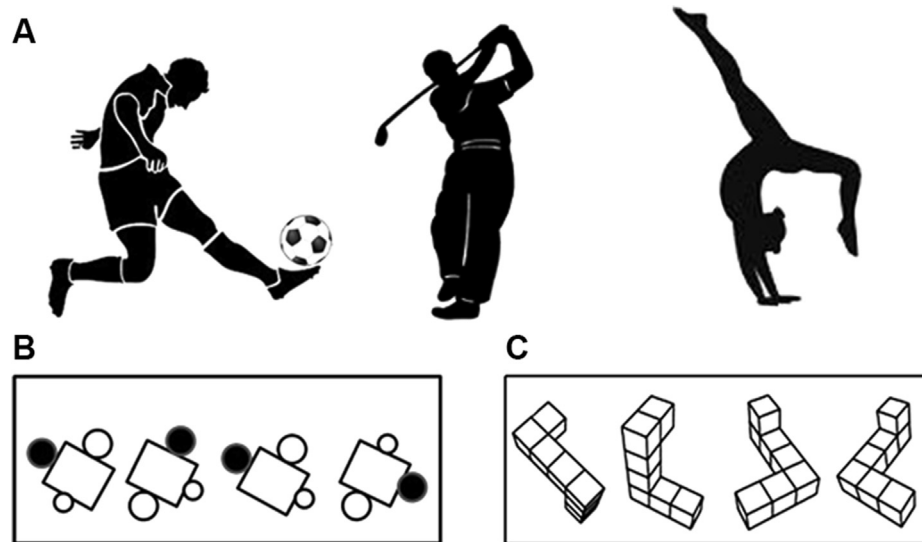


Fig. 1. Mental rotation associated with sports. Soccer, golf, and gymnastics (A) require spatial rotation. The tasks include simple 2-dimensional stimuli (B) or complex 3-dimensional stimuli (C). In tests, two or more objects which were either identical or mirror images of each other were placed at different orientation in space with varying degrees of angular disparity.

than untreated female-to-male transsexuals but after 10 months of treatment the differences were reversed.<sup>26</sup> However, later studies of cross-sex hormone treatment showed no change in the sex-sensitive mental rotation ability,<sup>27</sup> particularly, no change in spatial abilities in male-to-female transsexuals under estrogen treatment.<sup>28</sup> It is worth to notice that the controversial findings of the effects of sex hormones on mental rotation may be well associated with whether the studies were done in subjects with physiological or pathological conditions, as well as at young or old ages.

### 2.1.2. Mental rotation in sports

Mental rotation tasks are broadly characterized as exercises and sports that require the mental repositioning of a 2- or 3-dimensional object. The mental rotation information is constantly used in sports in order to locate partners or opponents (team sports), identify the target location (shooting, golf), using landmarks in space (gymnastics).<sup>29,30</sup> In general, athletes exhibit differences in perceptual-cognitive abilities when compared to non-athletes. For example, gymnasts outperformed non-athletes in mental rotation task and in general better for pictures of human figures than for pictures of cubed figures,<sup>31</sup> suggesting variants of different mental rotation tasks should be applied in testing athletes, since they may have different outcomes depending on athletes' type of sport and/or the type of sport that is reflected in the mental rotation stimuli. Although mental rotation is developed at early stage during neuronal development period and the differences of mental rotation between athletes and non-athletes might be related to the subjects with better spatial ability, studies showed that the mental rotation is trainable for better. Therefore, this would be beneficial for our understanding of motor learning based on mental simulation and could contribute to the training of athletes from sports such as gymnastics, soccer, golf, and more for skydiving, scuba-diving, and climbing, where losses of

spatial orientation can be life-threatening.<sup>32</sup> Exercises also have positive impact on mental rotation. A study of juggling training showed that 3 months of juggling training improved performance on a chronometric mental rotation task with cube figures, compared to a control group which did not receive any training.<sup>33</sup>

### 2.2. Spatial navigation

Navigation tests, also called a way-finding, are commonly conducted by having subjects reconstruct a path through a map or real space. There are two different approaches that may be involved: egocentric and allocentric strategies (Fig. 2). An egocentric strategy involves more local landmarks and directional cues as personal directions. An allocentric strategy uses the absolute position of general landmarks, such as distance, as absolute directions.<sup>34</sup> Individuals with hippocampal sclerosis were more impaired in navigating through a virtual maze in which learning was associated with egocentric memory. The allocentric memory impairment is found in patients with extensive hippocampal sclerosis plus subcortical deterioration, suggesting a combination of hippocampal and cortical damage is associated with negative changes in allocentric memory.<sup>35</sup> Patients with temporal lobe epilepsy without hippocampal sclerosis do not display cognitive deficits of allocentric or egocentric memory.

#### 2.2.1. Sex differences in spatial navigation

Although males perform better than females in the navigation strategy, the relationship between navigation and one's level of testosterone has not been consistently demonstrated.<sup>36,37</sup> It is known that men tend to favor a more allocentric strategy (accurate judgments of distance), while women are more frequently egocentric (able to recall more street names and building shapes as landmarks) navigators.<sup>38,39</sup> However, it

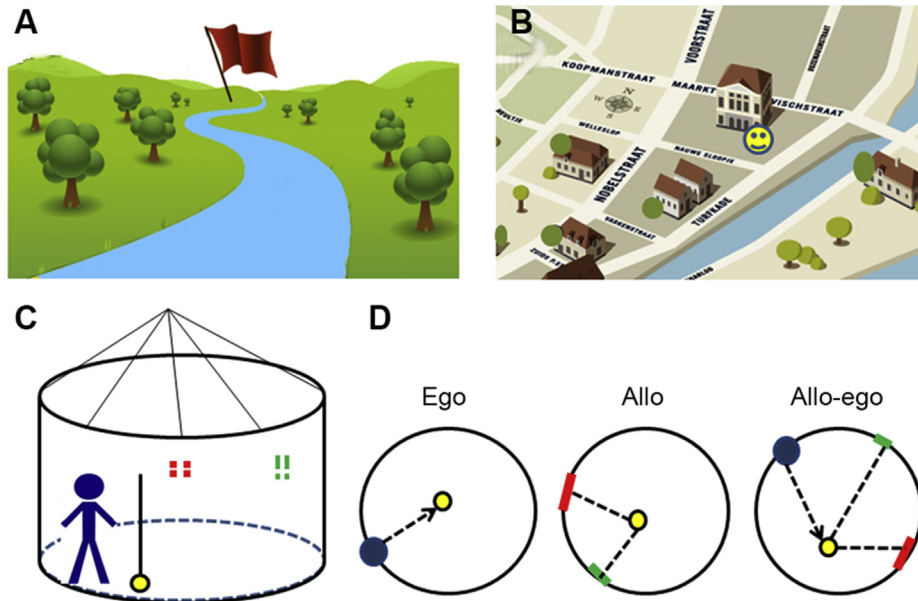


Fig. 2. Spatial navigation tests. There are virtual park (A) or virtual maze (B) tests as a determinant of capability in allocentric (allo) and egocentric (ego) memory, respectively. A hidden goal task is also commonly used. (C) Scheme of the individual subject in a real environment. (D) Navigation to a goal (small yellow circle) by the starting position (blue circle) as ego subject, or by the relation to two landmarks (red and green lines) as in the allo subject, or by both starting position and landmarks as allo-ego subject.

is worth pointing out that the outcome of sex-specific navigation test is closely related to the experimental conditions. For example, when test was performed within a single room or within an indoor environment without absolute directional cues, men and women perform the same.<sup>40,41</sup> On the other hand, men significantly outperform women in navigating through a large outdoor space.<sup>42</sup> Recent human studies using a computerized water maze to mirror rodent tests of object recognition and spatial navigation test showed a faster and more efficient performance by college-aged males compared to females of the same age.<sup>42</sup> Studies also reported that older adults' spatial navigation learning were preferentially related to processing of landmark information, whereas processing of boundary information played a more prominent role in younger adults.<sup>43</sup> Efficient spatial navigation requires not only accurate spatial knowledge but also the selection of appropriate strategies. Successful performance using an allocentric place strategy was observed in young participants, while older participants were able to recall the route when approaching intersections from the same direction as during encoding and failed to use the correct strategy when approaching intersections from new directions.<sup>44</sup> Aging specifically impairs switching navigational strategy to an allocentric navigational strategy. Indeed, a new walking spatial navigation test has been recently developed for early detection of cognitive impairment in an aging population.<sup>45</sup>

#### 2.2.2. Spatial navigation in sports

Athletes often give more accurate estimates of egocentric distance along the ground than do non-athletes, particularly in the sports taking place in highly standardized spatial settings, such as basketball and baseball. There is some evidence that golfers are much more accurate than others in estimating

distances on grass.<sup>46</sup> A study of spatial navigation differences in female athletes and non-athletes showed that the elite athletes, such as soccer, field hockey, and basketball, had faster walking times during the navigation of all obstructed environments by processing visuo-spatial information faster and navigating through complex, novel environments at greater speeds.<sup>47</sup>

### 3. Typical female-favored memory

#### 3.1. Object location or recognition memory

Object location is designed by presenting different arrays of common objects between the training phases. The test requires participants to identify the difference between the two selections. In human studies, the medial temporal lobe and perirhinal cortex are impaired in various types of object location tasks, but only when the objects have a high number of overlapping features. Meanwhile, patients with medial temporal lesions that are confined to the hippocampus showed normal performance on object location tasks regardless of the level of feature ambiguity.<sup>48,49</sup> Significant female advantages have been observed in several studies of object location memory.<sup>50–52</sup> This is opposed to mental rotation and navigation tasks, suggesting that object location differs from other spatial tasks in terms of its cognitive demands.

##### 3.1.1. Sex differences in object recognition

Females apparently outperform males in object location tasks. When geometric and non-geometric objects are both available for specifying location, men have been shown to rely more heavily on geometry compared to women and the sex differences in object location were also reported in young



children with boys relied more heavily than girls on geometry to guide localization.<sup>53</sup> Sex differences in the object recognition memory are also related to the type of objects. For example, studies found that men are usually more affective by plants whereas women are more sensitive with animals.<sup>54</sup> The object differences between males and females are further confirmed with recent studies that demonstrated an advantage for living categories in women while men showed an advantage for cars.<sup>55</sup> Moreover, a study of spatial object location memory using abstract design showed no sex differences in either the visual or spatial location tests.<sup>56</sup> All together, evidence suggests that stereotypical interests may play a role in these effects.

### 3.1.2. Spatial object location in sports

Object location or recognition is closely related to sports with gaze characterization, such as elite shotgun shooting. One study recorded point of gaze and gun barrel kinematics in groups of elite ( $n = 24$ ) and sub-elite ( $n = 24$ ) shooters participating in skeet, trap, and double trap events. They reported that in skeet, trap, and double trap disciplines, elite shooters demonstrated both an earlier onset and a longer relative duration of quiet eye than their sub-elite counterparts did, suggesting a longer quiet eye duration might be critical to a successful performance in all three shotgun disciplines.<sup>57</sup> Another sport is cricket which requires interception of a fast moving object, cricket ball. A recent study showed that elite cricket batsmen experienced no decrease in performance levels when hitting cricket balls delivered to them at approximately 30 m/s even when foveal vision was temporarily impaired by wearing contact lenses to induce myopic blur.<sup>58</sup> Depending on the spatio-temporal demands of the task and the intentions of the batsman a range of visual search strategies can be employed to support their actions.

## 3.2. Verbal memory

Two kinds of general measures of verbal memory have been used in most studies to identify sex differences. One is the Controlled Oral Word Association Test (COWAT) to test verbal fluency and another is the Rey Auditory Verbal Learning Test (RAVLT), also known as the California Verbal Learning Test (CVLT), which has participants recall a list of words.

### 3.2.1. Sex differences in verbal memory

Women outperform men in both measures. Interestingly, the female advantage in verbal memory is consistent throughout the lifespan,<sup>59,60</sup> suggesting circulating sex hormone independency. Women generally score higher than men on verbal memory tasks, possibly because women tend to use semantic clustering in recall. Studies showed that the sex differences in recall and semantic clustering in the verbal learning test diminished with a shorter word list in a relative small sample study.<sup>61</sup> A 10-year longitudinal study of over 600 nondemented adults, aged 35–80 years, found stable sex differences across five age groups—women outperformed men

on verbal memory, verbal recognition, and semantic fluency tasks, while men demonstrated better visuospatial ability.<sup>62</sup> Some studies showed that healthy elderly women have better immediate word learning,<sup>63</sup> verbal memory, and episodic memory compared to age-matched men.<sup>64</sup> However, a recent meta-analysis of neurocognitive data from 15 studies ( $n = 828$  men; 1238 women) showed that men modestly but significantly outperformed women in all of the cognitive domains been examined, including verbal and visuospatial tasks and tests of episodic and semantic memory, while age and minimal state examination (MMSE) were not associated with the male-advance in memory.<sup>65</sup> Some also reported better visual memory,<sup>66</sup> working memory,<sup>67</sup> and episodic memory<sup>67</sup> in elderly men than women. Furthermore, others have also reported no sex differences in the elderly for verbal memory.<sup>68</sup> So, there exists no clear pattern of sex advantages for memory in the healthy elderly, and any sex differences appear to be task dependent. A cross-sectional analysis of the association between sex hormones, metabolic parameters, and psychiatric diagnoses with verbal memory in healthy aged men showed that higher levels of serum sex hormone binding globulin (SHBG) were associated with a worse verbal memory,<sup>69</sup> suggesting levels of free testosterone influence male verbal memory. However, findings of sex differences in verbal memory in young adults or early adolescents are contradictory. Studies showed no association between the sex-dependent verbal memory and age, level of sex hormone, or puberty development in teenage boys and girls.<sup>70</sup> Furthermore, a recent study including 366 women and 330 men aged between 16 and 69 years of age, showed that women outperformed men on auditory memory tasks due to female advancement in verbal memory, whereas male adolescents and older male adults showed higher level performances on visual episodic and visual working memory measures.<sup>71</sup>

### 3.2.2. Verbal memory in sports

While there are no sports specific involved or not involved verbal memory, extensive studies showed sex differences on concussion outcomes between concussed male and female athletes, such as female concussed athletes have been reported to have greater neurocognitive impairments on reaction time and visual memory when compared with male concussed athletes.<sup>72,73</sup> However, it is unknown whether the sex differences in cognitive impairment induced by concussion in male and female athletes are associated with the male sports (football) which lacking of female players. A recent study included female and male concussed soccer players and found a significant between-patient main effect for sex on verbal memory, such as female athletes scored lower than male athletes.<sup>74</sup> While there is no knowledge of what causes the sex differences in verbal memory impairment between concussed male and female athletes, a recent study showed that shorter and intermediate sleep duration after concussion is associated with the lower score of verbal memory, and female concussed athletes often reported more symptoms of fatigue, headache, and sleep difficulties.<sup>75</sup>

#### 4. Conclusion

The differences in learning and memory between men and women are commonly recognized by general population as well as scientists. Males outperform females in spatial mental rotation and navigation tasks, while females often do better on object location or recognition as well as verbal memory tasks. Although it is known that the gender differences in the cognition started from early development stage and last throughout whole lifespans, recent studies of people with transsexualism and elite athletes demonstrated that sex hormone treatment and exercised might be able to alter the sterol sex-type cognition. In addition, it is worth to notice that many neurological diseases exhibit sex differences, such as women having a higher prevalence of Alzheimer's disease, a most common form of dementia in elderly than age-matched men. We believe that better understanding the biology of sex differences in cognitive function will not only provide insight into healthy life style, promoting gender-specific exercise or sports, but also is integral to the development of personalized, gender-specific medicine.

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